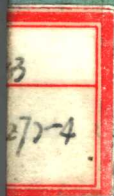


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## **PREFACE**

The leading scientists in the many different fields of geology were invited by the Organizing Committee to present a paper on a specific problem in present-day geological science at the 27th International Geological Congress. The published proceedings of the Congress consist of twenty-three volumes. Each volume is dedicated to a particular aspect of geology. Together the volumes contain all of the contributions presented at the Congress.

The Organizing Committee is pleased to acknowledge the efforts of all of the participating scientists in helping to produce these proceedings.

**Professor N. A. BOGDANOV**  
General-Secretary of the  
Organizing Committee

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# SUPERGENESIS AND SEDIMENTOGENESIS: TRANSPORT AND ACCUMULATION OF SEDIMENTS IN DIFFERENT ENVIRONMENTS

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## ABSTRACT

The conditions and factors governing weathering processes are stressed. The intensity of weathering and the depositional environment are expressed as a function of several identical or similar primary factors. Depositional environments may be roughly divided and interpreted according to the best possible known lithological data. Geochemical mega- and microenvironments exist in the weathering crust as well as in the sedimentary lithosphere. Objective lithological division and nomenclature is recommended for sedimentary rocks while interpretational terms should be reserved for the depositional environments.

## WEATHERING OF ROCKS AND MINERALS

Weathering of rocks and minerals, the so-called supergenesis or hypergenesis, is an important introduction preceding the formation of sediments. Weathering processes include all reactions running during the interaction between the uppermost part of the lithosphere and the hydrosphere with the atmosphere under the influence of solar energy. Water with acid forming constituents and the oxygen from the atmosphere are the main agents transforming various source rocks into three fractions: 1/ material in solution, 2/ newly formed minerals, 3/ relatively stable rockforming constituents, or resistates. Hydrolysis and gragmentation are the main weathering processes. Relatively stable constituents and newly formed minerals build the residual profiles. Only very small amounts of the material in solution remains in pore water.

The intensity of weathering  $I_w$  of the exposed rocks during the geological history of the Earth depends on the following primary factors: /1/ the amount of the accepted solar energy,  $E_s$  /and the resulting climate with its characteristic and determining amount of ran water and characteristic biosphere/; /2/ the chemical and physical properties of the atmosphere and the hydrosphere,  $A + H$ ; /3/ the material composition and the texture of the exposed rocks,  $R$ , including the system of cleavage; /4/ the energy of tectonic movements,  $E_m$ ; /5/ the duration of the action,  $t$ . This complex relation can be generally written as:-

$$I_w = f / E_s, A + H, R, E_m, t /.$$

The higher the temperature, the amount of the soaked rain water, its acidity, drainage, the chemical instability of the exposed rock and duration of the action the stronger is the destruction.

The ratio of the intensity of physical destruction or fragmentation to the chemical destruction or hydrolysis of a certain rock depends on the  $E_m/E_{ch}$  ratio, where  $E_{ch}$  means the energy of chemical destruction. This very important ratio valid for any region of the continental earth crust controls the erosion and formation of different arenites, muds and related sedimentary rocks. The increasing value of the  $E_m/E_{ch}$  ratio gives better chance to the accumylation of arenites rich in relatively unstable constituents, i.e. greywackes and arkoses. The region of the low  $E_m/E_{ch}$  ratio is favourable for the accumulation of quartz sands. Although a small  $E_m/E_{ch}$  ratio allows the decomposition of the exposed rocks to be stronger and deeper, the production of mud-forming constituents, i.e. the silt and clay silicate fraction may be more intensive in the region controlled by higher tectonic energy, due to the huge bulk of the denuded material during the same time interval.



The five above-mentioned primary factors modify the origin of the globally extensive soil profiles or residual rocks up to several tens of metres thick. This so-called weathering crust or the mantle of weathering is characterized by two regular zonations: the climatic zonation parallel to the equator, and the vertical zonation where we may follow a transition from the fresh rock in the deepest part of the profile, through the disintegration zone, to the zones in which the characteristic clay minerals occur, sometimes along with free hydroxides of iron and aluminium and further minerals /Fig. 1, Strakhov, 1962/. The third regular zonation, vertical too but much deeper, develops in the sedimentary lithosphere during diagenesis.

#### The Influence of Solar Energy, Hydrosphere, Atmosphere and Biosphere

The largest amount of the accepted solar energy, and the resulting climate with a maximum of precipitations are characteristic of the equatorial forest zone where the profiles of the weathering crust rich in kaolinite attain greatest thicknesses. As the position of the equator and thus also of all the climatic zones varied in geological history, there existed a global oscillating evolution of the weathering crusts and continental sediments accompanying. The plants and their substantial influence on the formation of the crust of weathering revealed on the continents only from the Devonian. The substances produced by the continental plants during their life and released after their extinction, are taken down by rainwater, and contribute to its acid reaction at the initial stage of infiltration into the rocks. In recent times, during the weathering processes, the concentration of the hydrogen ions in rainwater varies considerably in dependence on the geographical position and the season of the year, the pH values being between 3.0 and 9.8. The pH of rainwater at equilibrium with atmospheric carbon dioxide at a temperature of 25°C is 5.7.

The evolution of the Earth's atmosphere from that rich in CO<sub>2</sub>, ammonia and nitrogen through that composed of nitrogen, carbon dioxide and a small portion of oxygen up to the present-day atmosphere, developed in the Middle Devonian, with 78 per cent nitrogen, 21 per cent oxygen, 1 per cent argon and a small admixture of other subordinate constituents probably influenced the weathering processes /Kazanskiy, 1979; Degens, 1981/.

### The Influence of the Composition of Rockforming Constituents and the Texture of the Source Rock

The silicates together with quartz and volcanic glass build up more than 90 bulk and mass per cent of rocks of the earth's crust. The rockforming silicates and volcanic glass are variously stable during weathering or low-temperature hydrothermal decomposition in dependence on several variables.

Resistance of each crystalline silicate /I<sub>KO</sub>/ may be calculated according to the equation:

$$I_{KO} = \frac{200 \times \sum \text{of moles of oxides A each of which is multiplied by the corresponding } Z/r - C \times Z/r \text{ for } H^+}{\text{moles} / \sum \text{of all oxides A+B where each is multiplied by the corresponding } Z/r/}$$

where A are the oxides whose cations are relatively easily released from silicates in water and are rather mobile /esp. FeO, MnO, MgO, CaO, SrO, BaO, NiO, Li<sub>2</sub>O, Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>/; B are the oxides whose cations come into solution with difficulty/SiO<sub>2</sub>, ThO<sub>2</sub>, ZrO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, Cr<sub>2</sub>O<sub>3</sub>, B<sub>2</sub>O<sub>3</sub>, V<sub>2</sub>O<sub>5</sub>, Ti<sub>2</sub>O<sub>3</sub>/;

C - hydroxyl /OH/ and zeolite water;  
Z - the valence or charge of a cation;  
r - radius of the cation.

The larger the value of I<sub>KO</sub>, the smaller the chemical resistance during weathering.

The chemical stability of silicates during weathering is influenced especially by the percentage of  $\text{SiO}_2 + \text{Al}_2\text{O}_3$ , due to the high bond energies between Si-O and Al-O, and of hydroxyl or zeolite water. Fig. 2 shows the differences between the stabilities of all the groups of the rockforming silicates in the aqueous environment based on the relation between  $I_{\text{KQ}}$  value and the  $\text{SiO}_2 + \text{Al}_2\text{O}_3$  content /Konta, 1982/. The index may be extended to silicate rocks as to other rocks. The coarse-grained rocks, however, undergo weathering more rapidly than the fine-grained rocks of analogous mineral and chemical compositions. The clay minerals as the main newly formed constituents of the weathering crust, especially the dioctahedral species, mostly belong to the fairly stable up to ultrastable silicates in the aqueous environment. This is why their predominant portion after erosion finds their sink in lakes, seas and the oceans. Similarly, zeolites are highly stable in the aqueous environment.

#### Geochemical mega- and microenvironment

Chukhrov /1978/ has shown the decisive influence of the geochemical megaenvironment of the primary silicate /and other/ rocks upon the formation of regular associations of clay minerals and hydroxides in the weathering crust profiles. The crystallochemical composition of the newly formed minerals in the individual vertical zones of a weathering profile depends primarily on the concentration of iron and aluminium in the fresh source rock. The amount of penetrated water and the intensity of decomposition have a favourable influence upon the thickness of the individual zones. Chukhrov's synthesis has been supplemented with the concept of "geochemical microenvironment" /Konta, 1979/. This concept is based on the differences in the mineral associations found by X-rays, the scanning electron microscope and the electron microprobe. They occur as clay pseudomorphs after the crystals of acid plagioclase and potassium feldspar representing the main rockforming constituents in the weathering profiles. This fact furnishes

evidence that the influence of the original geochemical environment remained in the small volume of the individual original crystals for a long time up to the advanced weathering stage of kaolins. A perfect chemical homogeneity is hardly attained in any zone of the weathering profile.

A remarkable fact is that the lack of cleavage, continual cracks and microcracks in the volcanic glass of any chemical composition causes a reduced drainage of water during weathering, so that the environment is favourable for the formation of montmorillonite or in the case of a nearly zero removal of the dissolved matter even only for the formation of a zeolite.

### Erosion and Transport

Erosion and denudation of residual rocks and thus also soils depends on the same primary factors leading to the formation of a weathering crust. In the geological history, the transport of the detrital material is carried out predominantly by water, to a lesser degree by air and glaciers. The intensity of erosion rises with the total amount of annual precipitations, with the reduction of the vegetation cover, with the intensity of the tectonic energy and with the increasing height differences in the region, with the decrease of the cohesion, the compaction or the cementation of the residual and other rocks /see Hjulstrom, 1939; Sundborg, 1956/ and finally with the length of time.

The most common aqueous flows are rivers, tidal and storm currents with important action of waves. Sediment-gravity flows, in particular turbidity currents and debris flows arise under the direct action of gravity.

Many features observable and measurable on the internal and external structures of the sedimentary units up to the individual textural components /coarse fragments, sand grains, particles/ serve to the differentiation between the transportational and depositional environments. Bedding and lamination, current ripples,

sand waves, dunes, cross stratification, antidunes and antidune cross bedding, wave-formed ripples and cross lamination belong to the most important depositional sedimentary structures. The post-depositional sedimentary structures are slump folds, convoluted bedding, load casts, sandstone dykes, dewatering structures and various biogenic sedimentary structures.

A lot of work has been done investigating the arenites and expressing their size distribution by various statistical parameters /e.g. Griffiths, 1967/. Graphic expression according to Visher /1969/ enables to distinguish the size populations in the arenite studied, i.e. what portion of the sediment was moved by traction /or rolling or sliding/, by saltation and in suspension, and also to differentiate the eolian sands from the aquatic sands. The relationship between the mud remaining with the sand grains, the sorting and the rounding of sand grains, expressed in the terms of the textural maturity of arenites, reflects the amount of the energy input /Folk, 1951/ and is often used in the interpretation of the transportational and depositional environments. The quality of the clastic sand grains, especially of quartz, studied by the optical and scanning electron microprobe enables the distinction between the transport by water, air and glacier. Gradational structure or graded bedding is characteristic of turbidity currents.

### Depositional Environments

Depositional environments may be divided roughly according to the lithology of the respective sediments, i.e. the textural features, represented mainly by the size of the textural components, the quality of their surface and their material composition, and also by the structural features of the sedimentary bodies. To the textural components belong any clastic detrital material and any cementable material including the skeletons of organisms or their fragments. This point of view enables the distinction of the depositional environments of the following groups of sediments:

/1/ Rudites and arenites /gravels and sands and their consolidated equivalents/. /2/ Lutites and pelites /muds and clays and their consolidated equivalents/. /3/ Zeolite sediments. /4/ Bauxites, ferrolites and manganolites. /5/ Caustobiolites. /6/ Phosphorites. /7/ Siliceous sediments. /8/ Carbonate sediments. /9/ Saline sediments /evaporites/.

The depositional environments of these groups of sediments may be divided into continental, marine and transitional environments. The main continental environments are fluvial and glacial streams, lakes and the eolian sand flats of deserts. The typical marine environments are tidal flats, sabkhas, beaches and barriers, shallow shelves and epeiric seas, bathyal-abyssal sites of pelagic, hemipelagic and turbidite sedimentation. The transitional environments are represented mainly by estuaries, deltas and lagoons /see more in Reineck, 1973/.

Field work, megascopic and microscopic descriptions or measurements, various geochemical data, paleontological descriptions and identification of the associations of rockforming constituents help to distinguish between facies and probable depositional environments of any sedimentary rock built during the geological history. However, much energy had to be put into the research of the modern sediments that serve for the necessary comparison. In this respect continental, transitional and near-shore environments are better known than the pelagic oceanic environments. Some authors distinguish lithofacies from biofacies, their mutual correlation being not yet satisfactorily elaborated.

Sedimentologists build on the assumption that the conditions existing in any depositional environment, i.e. physical, chemical and biological factors, determine the properties of the sediment formed in these conditions. Similar primary factors are decisive for the depositional environments like those that exist in the weathering processes of the lithosphere /p. 2/. Only point /3/ should be modified: "the amount,

composition and structural features of the detrital material and the intraformational material, DM + FM". Then we may express the second simple relation for any depositional environment  $/D_e/$ :

$$D_e = f / E_s, A + H, DM + FM, E_m, t/.$$

What do we understand by the physical and chemical properties of the atmosphere and the hydrosphere where most depositional processes occur? They are especially the movement energy of the air or water streams, chemical composition of the atmosphere, depth of water and the degree of agitation, temperature, salinity, Eh and pH above and in the sediment. The high rate of the sediment supply is as important for deposition of the clastic sediments, such as gravel, sand, mud and clay as are the low rates favouring environments of high-percentage limestone, phosphorite, siliceous sediment, saline sediment etc. Similarly important is the extent and the thickness of the moving glaciers and the rock basement for the moraine lithology. Various lithofacies of ferrolites, manganolites, sulphur compounds and caustobiolites are very sensitive on the activity of oxygen expressed by Eh.

However, in many sedimentary bodies not only the conditions determining the megaenvironment but also microenvironmental conditions exist. There is another similarity to the mega- and microenvironments in the residual profiles. The formation of microenvironments under conditions differing from those of the mega-environment, usually takes place in a stage of diagenesis. Nevertheless, the causes of these diverse reactions in the microenvironments exist in many cases as early as during the deposition. This holds e.g. for carbonate nodules in muds, pyrite or other sulphide concretions, siliceous nodules in some limestones, occurrence of zeolites etc.

One sole typical depositional environment does not exist in the formation of any of the nine lithological groups of sediments. Thus for example the depositional

environments of coarse and medium-grained clastic sediments, i.e. rudites and arenites are: (a) fluvial streams, (b) lakes, (c) estuaries, (d) deltas, (e) barriers, beaches, tidal flats of marine shorelines, (f) shallow marine shelves and epeiric seas, (g) continental margins and deepwater basins, (h) deserts, (i) glacial environments.

The silt and clay terrigenous clastic particles are largely transported in suspension by river streams. The depositional environments of muds and clays are various quiet low energy sites of the basins. The matter in suspension finds deposition in floodplains, lakes, estuaries, deltaic environments, lagoons, nearshore and offshore marine environments. The dust containing silt grains and clay particles may be deposited on land as loose or carried into the oceans where it is mixed with other pelagic or semipelagic sedimentary material. Mud can be also redeposited in viscous, sediment-rich and water-poor flows known as mudflows.

From the large number of the depositional environments and lithogacies of all the groups of cementable sediments let us mention at least those for carbonate sediments: I. Non-marine carbonate sediments: lacustrine limestones, formed as inorganic precipitates, algal limestones or aragonite inclusive of lime muds, stromatolite "reefs" and coid shoals, skeletal calciarenites. II. Marine carbonate environments and lithofacies, beginning from the shoreline and continuing to the open sea: tidal flats, channels, ponds, beaches, marshes, sabkhas; lagoons, behind barriers /carbonate muds/; open platform with the shoal water /carbonate sands and coid shoals/, quiet water /with carbonate muds/; shelf margin /reefs and carbonate sand shoals/; deeper parts of the sea basin with fore-reef talus, deeper-water buildups /e.g. mud mounds/, open sea /pelagic carbonate oozes and turbidites/.



## CONCLUSION

Many methods and more or less expensive devices are now used for obtaining the lithological, geochemical and paleontological data and observations necessary for the characterization of the weathering and depositional environments in the geological past. The field work and the strategic sampling should never be neglected. There are very few environments where only one specific lithologic type of sediments can settle. It is recommended to prefer objective lithological nomenclature designating the sedimentary rocks to the interpretational terms that should be left for the depositional environments.

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